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Innovation in Aerodynamic Design Features of Soviet Missiles

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Wind tunnel investigations of some tactical and strategic missile systems developed by the former Soviet Union have been included in the basic missile research programs of the NACA/NASA. Studies of the Soviet missiles sometimes revealed innovative design features that resulted in unusual or unexpected aerodynamic characteristics. In some cases these characteristics have been such that the measured performance of the missile exceeds what might have been predicted. In other cases some unusual design features have been found that would alleviate what might otherwise have been a serious aerodynamic problem. In some designs, what has appeared to be a lack of refinement has proven to be a matter of expediency. It is a purpose of this paper to describe some examples of unusual design features of some Soviet missiles and to illustrate the effectiveness of the design features on the aerodynamic behavior of the missile. The paper draws on the experience of the author who for over 60 years was involved in the aerodynamic wind tunnel testing of aircraft and missiles with the NACA/NASA.

I. Introduction

The use of missiles in warfare was effectively demonstrated by Germany in World War II with the vengeance weapons V-1 and V-2. Since that time the incorporation of missiles into the worldwide weapons system arena has progressed at a rapid rate. Following WW II both the United States (U.S.) and the Soviet Union (USSR) acquired much of the German technology and began developing missiles for homeland defense. A variety of missiles have been developed by the former Soviet Union beginning in the 1950's with the SA-1 Guild and the SA-2 Guideline air-defense systems. Missiles have been developed for use as either offensive or defensive systems. Missiles cover a wide range of sizes that vary from small, man-portable types to very large surface or air-launched types. The Soviet Union often displayed missiles in traditional parades through Red Square. Many of these missiles came as a surprise to the Western world. In order to better understand the rationale behind these systems, wind tunnel tests of simulated models of some Soviet missiles were conducted by the NACA/NASA. In the conduct of these tests there was often some revelation of Soviet missile design philosophy and techniques. It is the purpose of this paper to describe some of the Soviet missile systems that often displayed innovative design features

II. Discussion

The first new USSR missile system to come to the attention of NACA/NASA was a large surface-to-air missile (SAM) that was given the NATO code name of Griffon. The missile, first seen in a Moscow parade in 1963, was quite large and was substantially different from other known Soviet SAM systems, the SA-1 Guild and the SA-2 Guideline. The missile was simulated in model form and was subjected to supersonic wind tunnel tests at the NASA Langley Research Center. The tests indicated very good stability and control characteristics and good maneuverability. However, the missile never entered the Soviet inventory and was apparently used as a flight test vehicle to gather information for use in the design of missiles yet to come. It may be that a missile to benefit from such information was the SA-5 Gammon, a high-speed, high-altitude missile that appeared in 1967.

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In some parades in the 1960's an unusual modification to the SA-2 was displayed. The missile was shown with rather large external pipes mounted on the body. It was determined that a fuel tank had been added in the forebody region and a large external pipe was used to move fuel back to the aft rocket motor. Wind tunnel tests of the missile indicated that the aerodynamic center moved forward with increasing speed. In flight when fuel was burned from the forward tank the center of gravity would also move forward so that a low stability level could be maintained and maneuverability enhanced. Another unusual feature of this missile was the use of asymmetric wing panels. Further wind tunnel tests indicated that the addition of the external pipes had induced a rolling moment and that the roll was exactly offset by the wing asymmetry. An innovative design concept with one asymmetry being used to offset another asymmetry.

A new field-mobile SAM designated the SA-3 Goa was displayed in the November 1964 Moscow parade. The missile, at first glance, appeared to be relatively crude. The wing attachments complete with large bolt heads were exposed to the air stream. In addition, external control rods that were used to actuate wing flap controls were also exposed to the air stream. There was some thought in the Western world that the missile was cheaply constructed. This apparent lack of refinement, however, was probably a matter of expediency to the Soviet designer. The missile, after all, is a throw-away item and the unsightly protuberances are of little concern if they do not impede the mission. A model of the missile, complete with the protuberances, was constructed at NASA-Langley and tests were conducted in the Langley UPWT. The external control rods were simulated on the model and were used for setting the wing flap controls. The tests indicated good stability and control characteristics and maneuverability that was generally as good or better than other Soviet or U.S. SAM's.

An innovative missile concept introduced in 1967 was designated the SA-4 Ganef. Previous Soviet SAM's were propelled with a two-stage tandem rocket system. For these missiles an aft-mounted rocket provided the initial boost and then dropped off leaving an internal rocket for sustained flight. For the SA-4 the initial boost was provided with four solid-propellant rockets attached externally to the body. After boost, the external rockets fell away and sustained flight was maintained with a ram-jet engine in the main body that was fed with air from a nose inlet.

A new high-speed, high-altitude interceptor missile appeared in the 1967 parade that was designated the SA-5 Gammon. It was believed that the SA-5 was derived from the Griffon missile that was seen in the 1963 parade. From the size and general arrangement of the SA-5 it was thought that a particular purpose for the missile might be to intercept supersonic reconnaissance aircraft such as the Lockheed SR-71. One innovative feature noted on the SA-5 was the design of the tail control fins. The tail fins were composed of two sections that were connected with a torsion bar arrangement. In the lower dynamic pressure range the tail would deflect as a single unit. In the higher dynamic pressure range a point would be reached when the torsion bar strength would be exceeded and a section of the tail would be deflected in such a direction as to reduce the hinge moment. This action is similar to the spring-tab balance arrangement found on some aircraft. Managing the control hinge moment is an important consideration when flight over an extensive range of speed, altitude and dynamic pressure are expected.

Another unusual missile seen for the first time in the November 1967 Moscow parade was designated the SA-6 Gainful. The missile had small cruciform wings mounted near the mid-body to provide primary control and fixed cruciform tails at the rear. The missile had four rather large external pipes mounted on the body that extended from just forward of the wings to a point just forward of the tails. As seen in the parade, the forward ends of the pipes were faired over and the aft ends appeared to turn into the body. The purpose of these large pipes was the cause of some speculation on the part of missile designers in the Western world. Possible purposes that were considered included their being a part of the guidance and sensing system, a part of the warhead system, a part of the fuel system, a part of the propulsion system, and so on. A model was built for wind tunnel testing at NASA-Langley. Initial tests were made with the faired nose on the pipes as seen in the parade. These tests indicated very good stability, control and maneuver characteristics. The mid-body wings were deflected as controls and produced substantial increments of lift with little angle of attack change of the body. The flight path could thus be changed by

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translation rather than by angular rotation. This added some thought to the possibility that the four pipes were part of the guidance system and would allow seeking in four quadrants around the missile. Subsequent pictures became available in which the nose fairing of the pipes were removed and an air inlet was revealed. The pipes were then found to be air ducts that transmitted air aft to the vicinity of the propulsion system. It was then disclosed that the missile had an innovative propulsion system referred to as a ducted rocket. This system had a solid propellant rocket at the base of the body that was used for the first stage boost. Upon burnout the rocket was expended and the rocket chamber became the combustion chamber for a ramjet using ram air from the four external ducts.

Among the smaller air-defense missile was the man-portable, shoulder-launched SA-7 Grail. The SA-7 was a spin-stabilized missile that required a rolling motion to maintain stability. It was discovered that the rolling motion was produced in a very unique manner. Some known spin-stabilized missiles achieved the required roll rate by using asymmetrical airfoil shapes on the tail fins or by placing the tail fins at a slight angle of attack. Such a technique does produce a rolling motion but the roll rate varies with missile speed and angle of attack. The SA-7 tail fins, however, had symmetrical airfoil shapes and were set at zero angle of attack but were inclined, from the body. That is, when viewed from the rear, the tail fins were not normal to the body but each were inclined at a dihedral angle of about 15 degrees. This inclination resulted in the angle between the tail fin and the body being less than 90 degrees on one side and greater than 90 degrees on the other side. As a result the local air stream velocity near the base of the fin was slightly increased on one side of the fin and slightly reduced on the other side. This resulted in a difference in pressure near the base of the tail that produced a side-force on the fin that, in turn, provided a rolling moment to the missile. This arrangement was reproduced with a model in the wind tunnel and it was found that not only was a proper rate of roll created but that the roll rate was invariant with angle of attack and missile speed. Thus the control system required for the missile in flight was simplified.

Subsequently another roll-stabilized missile was discovered that also had an unusual system for providing the required roll. This missile, the AT-6 Spiral was a tube-launched anti-tank weapon that was to be carried by a helicopter. The Spiral had four curved wrap-around fins to permit tube mounting. When launched from the tube the fins unfolded from the body and revealed an inner surface with precisely beveled leading and trailing edges. Wind tunnel tests indicated that the beveled fins provided a pressure distribution that promoted a constant rate of roll as required for stabilization.

An earlier anti-tank missile that has been subjected to wind tunnel tests is the AT-2 Swatter. The Swatter may be launched at ground level toward a ground-level target. Actually this requires very good cruise performance to achieve a significant range when you consider the missile weight and the very low flight altitude. For this mission the missile has a very blunt nose to preclude glancing at impact and has very large unswept wings to generate the necessary lift. While the AT-2 may be considered a bit ugly it is, nevertheless, a good example of the Soviet desire to accomplish the mission with little regard for the looks of the missile.

In the category of true long-range cruise missiles, the AS-5 Kelt is an interesting design. The Kelt was an air-launched anti-shiping missile that was stated to cruise at a Mach number of 1.2. The Kelt resembled an aircraft with a swept wing and aft tail surfaces. The forebody was quite blunt and this raised doubt in the Western world that supersonic speeds could be achieved. A model was constructed and tested at NASA-Langley in a transonic and a supersonic wind tunnel. The tests indicated a surprisingly high drag-rise Mach number of 0.95 and supersonic flight was easily obtainable. An examination of the Kelt transonic area distribution revealed a smooth elliptical shape with the maximum thickness near the mid-length station - a shape that theoretically is ideally suited for low minimum wave drag. To achieve such an area distribution requires careful attention to the planform and profile of the wing and tail surfaces and to the placement of these surfaces. The tests also indicated that a positive pitching moment occurred at zero lift so that the missile could be trimmed with zero control deflection at the lift coefficient for the maximum lift-to-drag ratio.

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Another example of innovative Soviet design was discovered in wind tunnel tests of the Vostok reentry vehicle. (RV). In the early stages of space exploration both the U.S. and the USSR achieved orbital flight and were developing man-carrying vehicles to reenter the earth's atmosphere. The U.S. reentry vehicle shape was basically conical and, with an elaborate control system, was required to reenter with the heat-shielded base forward. The USSR RV was a slightly blunted spherical shape with heat shielding on the blunted surface. Thus the RV was required to reenter the atmosphere with the blunted surface forward. Press photographs of a Vostok RV following an earth landing made it possible to determine the blunted spherical shape. A wind tunnel model of the RV was constructed and tested at NASA-Langley for transonic and supersonic speeds. The results indicated a negative lift-curve slope for the blunted sphere so that with the center of gravity placed behind the center of pressure, the shape was inherently stable with the blunted heat shield surface forward. The shape would then automatically enter the atmosphere with the heat shield surface forward and no elaborate control system was required.

III Epilogue

Following World War II the Soviet Union began an extensive build up of military strength. A substantial portion of this buildup was devoted to missile systems. Quite often new missile systems would be revealed for the first time in the annual parades in Red Square. The Western world would often ponder the new designs and some speculation would arise regarding the purpose and the capability of the new systems. It was generally possible to use the parade information to design and fabricate models of some missiles for testing in NASA wind tunnel facilities. Many such tests have been conducted for the purpose of evaluating the Soviet missiles. In the course of these tests there have been many surprises regarding innovative design features of some systems. At first glance some design features appeared to be useless or even senseless. Further examination, however, would show that the unusual design features would alleviate a possible problem and enhance the overall effectiveness of the system.

It would be fair to say that these studies have been very helpful in defining the capability of some Soviet missiles. In addition the studies have been a useful addition to our own knowledge and, in a way, emphasizes a 'common sense' approach to missile design..

Bibliography

- Spearman, M. Leroy, "Some NASA Aerodynamic Research Related to Foreign Systems," AIAA 2004-108.
Spearman, M. Leroy. "Aerodynamic Characteristics of Missile Configurations Based on Soviet Design Concepts, AIAA 1979-1657.
Spearman, M. Leroy, " An Aerodynamic Assessment of Various Missile Configuration Concepts," NASA TM 84651, 1983.
Spearman, M. Leroy, " Historical Development of Worldwide Guided Missiles," NASA TM 85658, 1983.
Spearman, M. Leroy; and Collins, Ida K., " Aerodynamic Characteristics of a Swept Wing Cruise Missile at Mach Numbers from 0.50 to 2.86," NASA TN D-7069, 1972.
Spearman, M. Leroy; and Braswell, Dorothy O., " Aerodynamics of a Sphere and an Oblate Spheroid for Mach Numbers from 0.6 to 10.5 Including Some Effects of Test Conditions," NASA TN D-109016, 1993.

It should be noted that the papers included in the Bibliography contain extensive references to specific missile investigations.

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